

# Late-Glacial to Early Holocene Climate Changes from a Central Appalachian Pollen and Macrofossil Record

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A late-glacial to early Holocene record of pollen, plant macrofossils, and charcoal has been obtained from two cores from Browns Pond in the central Appalachians of Virginia. An AMS radiocarbon chronology defines the timing of moist and cold excursions, superimposed on the overall warming trend from 14,200 to 7500 <sup>14</sup>C yr B.P. This site had cold, moist conditions from ca. 14,200 to 12,700 <sup>14</sup>C yr B.P., with warming at 12,730, 11,280, and 10,050 <sup>14</sup>C yr B.P. A decrease in deciduous broad-leaved tree taxa and *Pinus strobus* (haploxylon) pollen, simultaneous with a reexpansion of *Abies*, denotes a brief, cold reversal from 12,260 to 12,200 <sup>14</sup>C yr B.P. A second cold reversal, inferred from increases in montane conifers, is centered at 7500 <sup>14</sup>C yr B.P. The cold reversals at Browns Pond may be synchronous with climate change in Greenland and northwestern Europe. Warming at 11,280 <sup>14</sup>C yr B.P. shows the complexity of regional climate responses during the Younger Dryas chronozone. © 1999 University of Washington.

**Key Words:** pollen, macrofossils, Appalachian Mountains, late-glacial, Holocene, Younger Dryas, Virginia.

## INTRODUCTION

Are the late-glacial climate oscillations that have been extensively documented in pollen records from western and northern Europe evident in eastern North America? Recent pollen records from Atlantic Canada (Mayle *et al.*, 1993), the northeastern United States (Peteet *et al.*, 1990, 1993; Maenza-Gmelch, 1997a,b), and the U.S. Midwest (Shane, 1987; Shane and Anderson, 1993) are interpreted as showing cold reversals that are synchronous with the European Younger Dryas chronozone (*sensu* Mangerud *et al.*, 1974). In addition, temperature estimates based on chironomid assemblages show cooling events of only 250 years duration that are recorded in Maritime Canada, called the Killarney Oscillation (Levesque *et al.*, 1993), and in Maine (Cwynar and Levesque, 1995). Therefore, evidence is accumulating that cold reversals interrupted the deglacial warming trend in eastern North America.

South of these glaciated regions, late-glacial cool or moist periods have been recognized in pollen records from Kentucky to Florida (Watts, 1980; Watts and Hansen, 1988; Wilkins *et*

*al.*, 1991; Watts *et al.*, 1992). Reviews of southeastern pollen records and climatic interpretations have been presented by Delcourt and Delcourt (1984, 1985), Overpeck *et al.*, (1989), Watts (1983), and Watts and Hansen (1994). However, the duration of these cool and moist periods and their possible connection to climate changes in the northern North Atlantic Basin have not been firmly established.

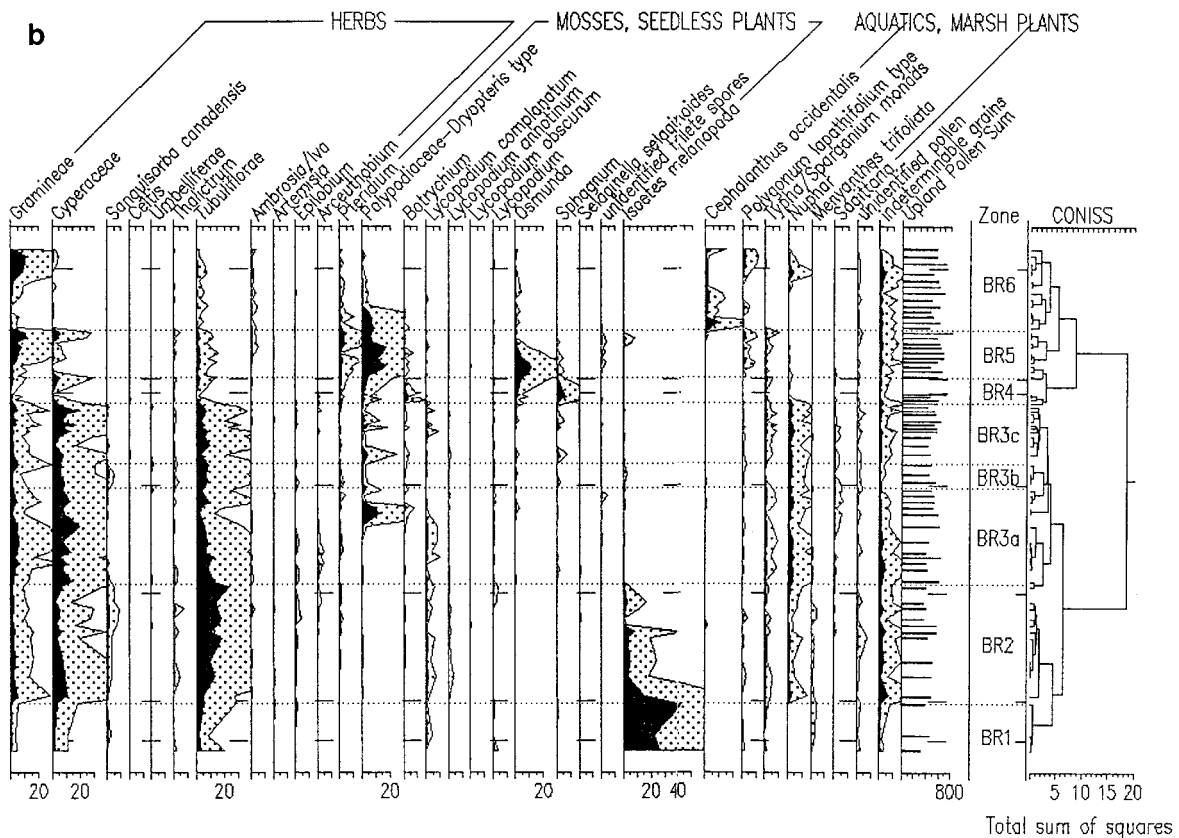
Identifying climate reversals on the order of 100 to 1000 years in existing unglaciated eastern U.S. records is difficult; slow sedimentation rates, combined with few radiocarbon dates, make it difficult to resolve events of this time scale. We have examined cores from a pond in the central Appalachians where accumulation rates averaged 70 cm per 1000 <sup>14</sup>C yr from 14,000 to 10,000 <sup>14</sup>C yr B.P. The pollen and abundant macrofossils, combined with AMS radiocarbon dating, have produced a detailed record of late-glacial to early Holocene vegetation change at this site.

## METHODS

Browns Pond is a 60 by 20 m basin, without inlets, in the central Appalachians of Virginia (38°09'17"N, 79°36'59"W) at 620 m elevation. Water depth is approximately 20 cm. The underlying bedrock is Upper Silurian limestone, sandstone, and shale (Bick, 1962). Despite the karst topography at this site, the colluvium is sandstone-rich and soils are acidic (T. Rawinski, personal communication, 1991). The closest weather station (Hot Springs, Virginia; 38°00'N, 79°50'W, 682 m) has an annual average temperature of 10.8°C and 1060 mm of precipitation (NOAA, 1983). The pond is covered with *Dulichium arundinaceum* (three-way sedge). The site is in the Ridge and Valley section of the Oak–Chestnut Forest region described by Braun (1950), and the trees immediately surrounding the site are typical of this region: *Quercus alba* and *Q. rubra* predominate. A more detailed description of the site and vegetation can be found in Kneller and Peteet (1993).

Previously, six cores were retrieved in a partial transect across the pond. The identification of pollen and plant macrofossils was concentrated on the central and longest core (BR89), which has a date of 17,130 <sup>14</sup>C yr B.P. at 400 cm depth





and 500  $\mu\text{m}$ . A volumetric estimate of charcoal content was made on the sediment fraction  $>500 \mu\text{m}$ .

Pollen classification follows McAndrews *et al.* (1988) and Faegri *et al.* (1989). *Alnus rugosa* and *A. crispa* types were distinguished according to Watts (1979). Morphological criteria exist to distinguish the pollen of three species of *Picea* now growing in eastern North America (Birks and Peglar, 1980; Hansen and Engstrom, 1985). However, the relevance of these criteria to *Picea* pollen from the southern Appalachians needs further evaluation (B. Hansen, personal communication, 1992); hence, *Picea* pollen identification remains at the genus level. The CONISS program for stratigraphically constrained cluster analysis (square root transformation) was applied to the upland pollen taxa to help define the local pollen assemblage zones (Grimm, 1987). Plant macrofossils were identified with the aid of Martin and Barkley (1961), Montgomery (1977), and Lévesque *et al.* (1988) and by comparison to the reference collection at Lamont–Doherty Earth Observatory. Nomenclature follows Fernald (1970) except where noted.

AMS radiocarbon-dated samples were identified macrofossils from trees or emergent aquatics; sediment was used when no macrofossils were available (Table 1). Previously, dates of macrofossils and bulk sediment from the same depths showed virtually no offset (Kneller and Peteet, 1993). AMS radiocarbon analyses were conducted by the Center for Accelerator

Mass Spectrometry, Lawrence Livermore National Laboratory, California, and the National Science Foundation Arizona AMS Facility. CALIB version 3.0.3c (Stuiver and Reimer, 1993) was used to derive the calibrated sidereal years (cal yr B.P., Table 1). The age model for Browns Pond is a straight-line interpolation between radiocarbon dates (plot of Deposition Time in Fig. 5).

## RESULTS AND INTERPRETATION

### *Pollen and Plant Macrofossils*

The radiocarbon dates for cores BR92 and BR91 are generally in chronological order (Table 1). The three nearly synchronous 10,000  $^{14}\text{C}$  yr B.P. dates, separated by 23 cm, in core BR91 either may indicate rapid sedimentation rates or be an expression of the radiocarbon age plateau identified at approximately 10,000  $^{14}\text{C}$  yr B.P. (Andréé *et al.*, 1986; Ammann and Lotter, 1989; Kromer and Becker, 1993). Without an independent age model, a plateau cannot be confirmed.

The pollen and plant macrofossil assemblages are interpreted in light of existing phytosociological studies that show tree distribution along elevational gradients in the Appalachians. Nearly pure fir (*Abies fraseri* or *A. balsamea*) stands characterize the highest elevation forests in much of the south-

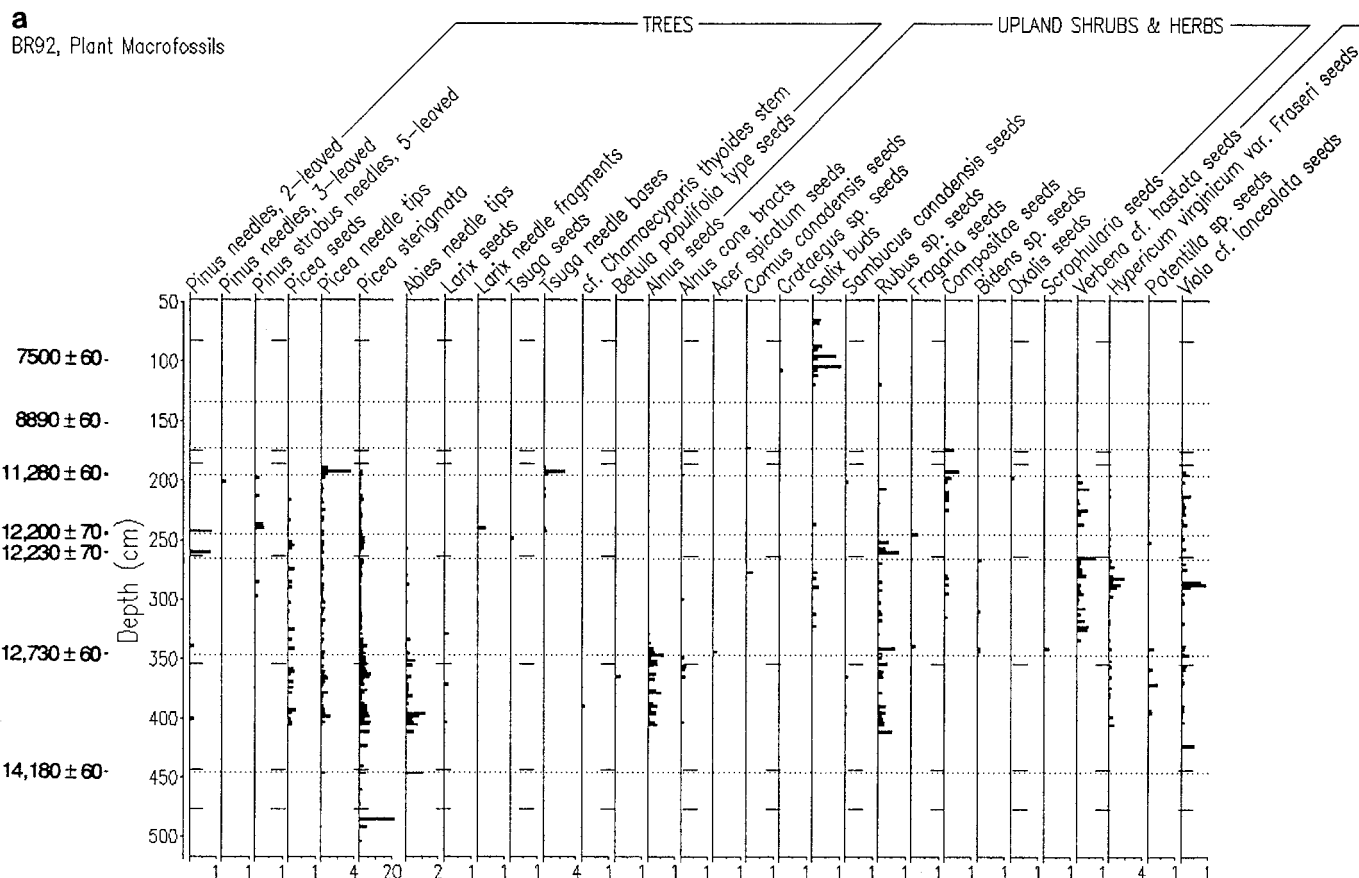


FIG. 2. Plant macrofossils counted in core BR92, per interval, and normalized to a 1 ml sediment volume. Charcoal concentration is given in  $\text{mm}^3$  per ml of sediment. The actual volume of each sediment sample is graphed on the far right in milliliters.

ern and northern Appalachians. *Abies* shows the greatest tolerance to cold; *Picea* usually is more abundant at elevations below *Abies* (Oosting and Billings, 1951; McIntosh and Hurley, 1964; Siccama, 1974; Reiners and Lang, 1979; Cogbill and White, 1991). In the Appalachian montane spruce–fir forest, unlike the North American boreal forest, *Picea rubens* is the dominant spruce species below approximately  $47^{\circ}40'N$  latitude, not *P. glauca* or *P. mariana* (Little, 1971; Cogbill and White, 1991). The *Picea*- and *Abies*-dominated stands grade into lower elevation stands containing deciduous trees. *Betula* is the one deciduous tree that is consistently found in many of the high-elevation forests, although the species may vary (e.g., *B. lutea*, *B. papyrifera*, *B. papyrifera* var. *cordifolia*, and *B. lenta*). *Fagus grandifolia*, *Acer saccharum* and *A. rubrum*, *Fraxinus americana*, *Tilia heterophylla* and *T. americana*, *Quercus rubra*, and the conifer *Tsuga canadensis* are frequent components of mid-elevation forests.

Alternatively, the taxa could be interpreted in light of their continental distribution, especially with reference to their high-latitude distribution. The elevation analogy is used here because the plant associations interpreted from the fossil record, between 12,700 and 7500  $^{14}\text{C}$  yr B.P., are very similar to associations found in the modern phytogeographic studies from

the Appalachians. Floristic differences exist between the high-elevation montane spruce–fir forest and the high-latitude or boreal forest. Many high-latitude taxa have their southernmost appearance in the central Appalachians (Gleason and Cronquist, 1991). We have not yet identified taxa, in the Browns Pond sediments, that are unequivocally boreal rather than montane. A major climatic difference is that the Appalachians at high elevations receive more precipitation than the high latitudes (Oosting and Billings, 1951).

**Zone BR1: *Picea*–*Abies* zone ( $\geq 14,180$   $^{14}\text{C}$  yr B.P.; BR92, 445 to  $\geq 485$  cm).** This zone is similar to the *Pinus*–*Picea*–*Abies* zone dating from 17,345 to 14,090  $^{14}\text{C}$  yr B.P. in core BR89 (Kneller and Peteet, 1993). One dissimilarity is that in core BR92, the percentages of *Picea* pollen (from 42 to 46%) are greater than *Pinus* pollen (from 29 to 38%), whereas in BR89 *Pinus* exceeds *Picea* pollen percentages. In both cores, the arboreal macrofossils are mostly *Picea* needles.

**Zone BR2: *Alnus*–*Picea*–*Abies* zone (14,180 to 12,730  $^{14}\text{C}$  yr B.P.; 17,000 to 15,000 cal yr B.P.; BR92, 445 to 346 cm).** This zone is defined by significant amounts of *A. rugosa*-type pollen, which reaches a maximum of 26%. It correlates with



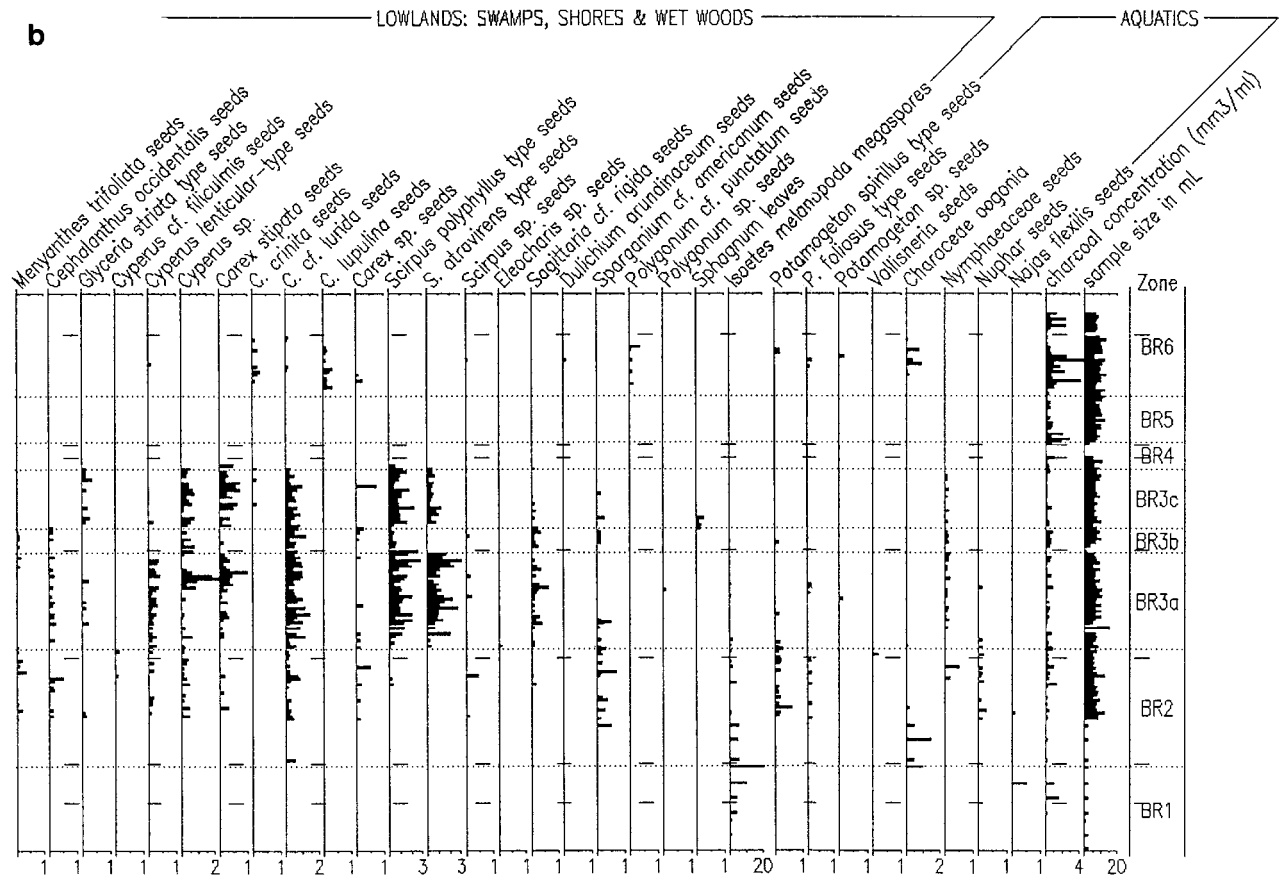


FIG. 2—Continued

the *Alnus–Pinus–Picea–Abies* zone in core BR89 dating from 14,090 to 12,810 <sup>14</sup>C yr B.P. (in which *A. rugosa*-type pollen ranged from 30 to 59% (Kneller and Peteet, 1993)). *Picea*, *Pinus*, and *Abies* reach maximum percentages of 32, 26, and 5.6, respectively. *Quercus* (3.0%) and *Betula* (2.6%) have the highest percentages of the deciduous-tree taxa. The herbaceous assemblage comprises a range of plants including Gramineae, Cyperaceae, Tubuliflorae, other Compositae, and *Nuphar*. Total upland pollen influx ranges from 1400 to 6000 grains/cm<sup>2</sup>/yr.

Macrofossil preservation is excellent. *Picea* needles and seeds are the most abundant macrofossils, followed by *Abies* needles and *Alnus* seeds and cone bracts. A few *Larix* seeds, fragments of 2-per-fascicle *Pinus* needles, and *Pinus* seed cone scales were found. The *Pinus* specie(s) could not be identified, as the needle fragments are small and the cone scales lack bracts, which can help identify species. A single *Betula* seed, *populifolia* type (Cunningham, 1957), was identified at 365 cm. Seeds of the shrubs *Sambucus canadensis* and *Rubus* sp., and herbs including *Hypericum virginicum* var. *Fraseri*, *Viola* cf. *lanceolata* and *Menyanthes trifoliata* are present. *Isoetes melanopoda* megaspores and microspores are abundant. This is

an amphibious species found in springtime saturated and summer dry conditions (Fernald, 1970; Boom, 1982). Aquatic seeds are common and include *Nuphar*, two species of *Potamogeton*, and *Najas flexilis*. Charcoal concentrations range from 0 to 1.2 mm<sup>3</sup>/ml of sediment.

A montane spruce–fir forest, established by 14,180 <sup>14</sup>C yr B.P., is indicated by the significant percentages of pollen from *Picea* and *Abies* and their abundant seeds and/or needles. Alder likely grew in moist soil near the pond. The array of arboreal and shrub macrofossils suggests a densely covered, mesophytic landscape surrounding the pond. The water depth was deeper than today, based on the presence of *Nuphar* and *Potamogeton*. Water levels were lower in summer than in spring, based on the presence of *I. melanopoda*.

The transition between pollen zones BR2 and BR3a is placed at 346 cm depth, between pollen samples at 343.5 and 348.5 cm depth, even though the CONISS analysis shows a distinct division between pollen samples at 348.5 and 361.5 cm depth. Our zone division is based on increases in percentage, concentration, and influx of *Quercus*, *Ostrya/Carpinus*, and *Fagus* that are evident in the samples starting at 343.5 cm depth (Figs. 1 and 5; Kneller, 1996).

a

BR91, Pollen Percentages

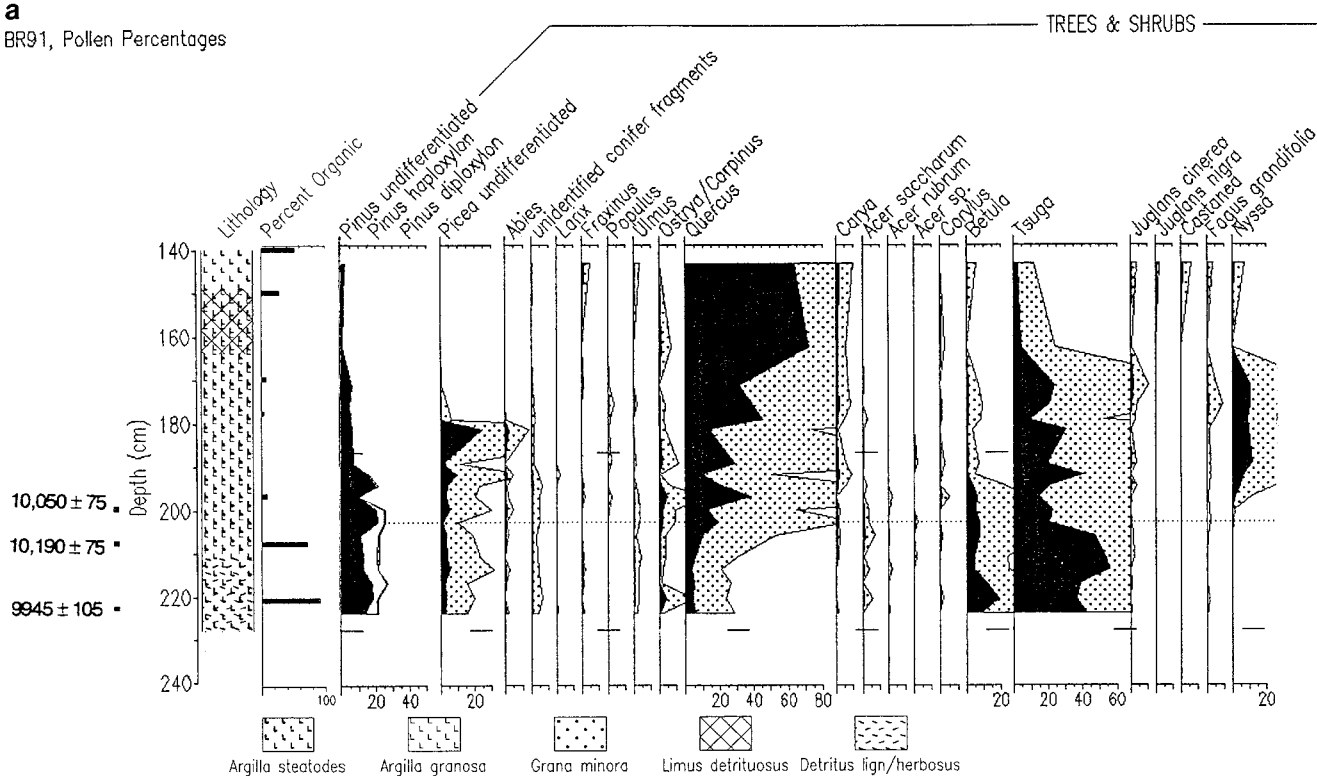


FIG. 3. Pollen percentage diagram from Core BR91, approximately 4 m west of BR92. Pollen percentages are calculated as they were for core BR92. The drive boundaries are at 87, 187, and 228 cm depths.

**Zone BR3a: *Picea*–*Abies*–*Ostrya/Carpinus*–*Quercus* zone** (12,730 to 12,260  $^{14}\text{C}$  yr B.P.; 15,000 to 14,320 cal yr B.P.; BR92, 346 to 266 cm). This zone is delineated by increases in some broad-leaved deciduous-tree pollen taxa. *Quercus*, *Ostrya/Carpinus*, *Fagus*, and *Juglans* reach maximum pollen percentages of 13.6, 3.8, 1.9, and 0.6, respectively, levels which likely show the taxon's presence (Davis and Webb, 1975; Delcourt *et al.*, 1984). *Picea*, *Pinus*, and *Abies* remain significant components of the pollen assemblage. *Nuphar* pollen percentages increase, whereas *I. melanopoda* microspores are absent. Other aquatics include *Typha/Sparganium*, *M. trifoliata*, and *Sagittaria*.

Pollen influx rises and ranges from 5900 to 22,000 grains/ $\text{cm}^2/\text{yr}$ . The influx increase is apparent in many taxa. The influx increase might be partly caused by increased slope inwash, or sediment focusing, for it coincides with higher sedimentation rates. However, whereas total pollen concentration is approximately constant across the zone BR2–BR3a boundary, the concentration of the different tree taxa varies. Pollen concentrations of *Ostrya/Carpinus* increase roughly 10-fold at zone BR3a's lower boundary, of *Quercus* increases about 4-fold, and of *Picea* and *Abies* increase roughly 2-fold. *Pinus* shows little change in concentration (Kneller, 1996). Maximum influx values for *Ostrya/Carpinus* are in this zone. Thus, a real increase in numbers

of deciduous trees, especially *Ostrya/Carpinus* and *Quercus*, likely occurred at 12,730  $^{14}\text{C}$  yr B.P.

Preserved arboreal macrofossils include *Pinus strobus* needles, 2-per-fascicle *Pinus* needles, and seeds and/or needles of *Picea*, *Abies*, and *Larix*. *Alnus* seeds decrease within this zone. A single *Acer spicatum* seed occurs at 343 cm. Seeds of several herbaceous plants become abundant: *Verbena* cf. *hastata*, *Carex stipata*, *Scirpus polyphyllus* type, *S. atrovirens* type, and *Sagittaria* cf. *rigida*. Aquatics include Nymphaeaceae seeds, along with scattered occurrences of *Potamogeton spirillus*-type and *P. foliosus*-type seeds. Charcoal concentration ranges from 0 to 0.75  $\text{mm}^3/\text{ml}$  of sediment.

A step toward warmer temperatures at 12,730  $^{14}\text{C}$  yr B.P. is inferred from the increases in *Quercus*, *Ostrya/Carpinus*, *Fagus*, and *Juglans* pollen and decreases in the seeds of *Menyanthes trifoliata* (a circumboreal aquatic). The array of conifer and deciduous taxa suggests a region similar to the transition from the subalpine conifer zone to the northern hardwoods–yellow birch–mesophytic forest zone found in the Balsam Mountains of Virginia (Rheinhardt and Ware, 1984), i.e., a climate cooler and moister than present. The marsh and aquatic taxa are typical of temperate eastern North American ponds. *Nuphar* seeds and pollen indicate water levels deeper than present.

Two small but distinct peaks in *Tsuga* pollen (in percentage

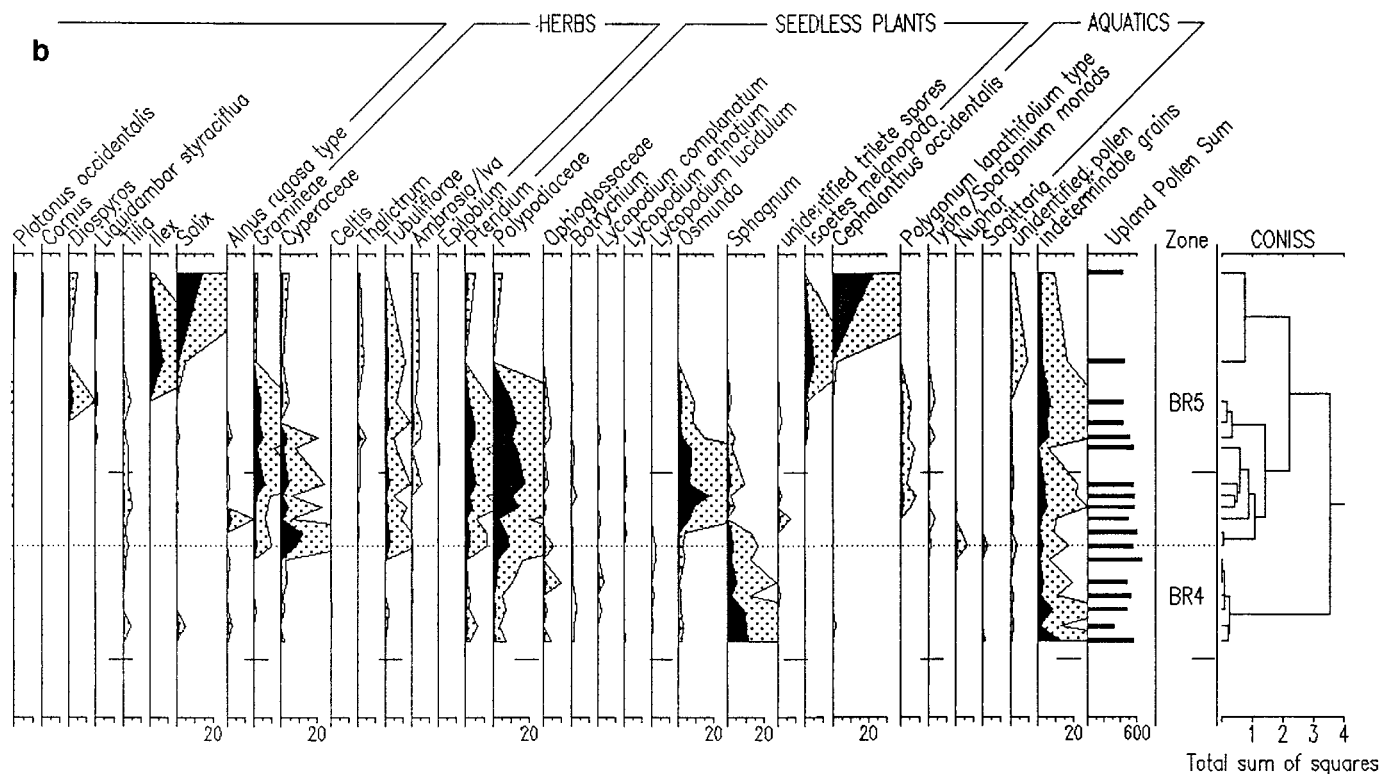


FIG. 3—Continued

and influx) are evident from 287 to 282 cm (two pollen samples of 9 to 12%) and at 267.5 cm (one sample of 3.7%). The first two occurrences of *Tsuga* needles at 282 and 267 cm depth are additional evidence that the *Tsuga* population increased at this site. The *Tsuga* peaks are also concurrent with increases in *Pinus* haploxydon-type pollen and *Dryopteris*-type spores and decreases in *Picea* and *Abies*. *Tsuga* and *Pinus strobus* are species found at elevations lower than *Abies* and *Picea* in the Appalachians. These changes may reflect warming temperatures, although replication in other cores from this site and neighboring sites is needed before a regional event can be inferred.

**Zone BR3b: *Abies*–*Picea*–diploxydon *Pinus* zone** (12,260 to 12,200  $^{14}\text{C}$  yr B.P.; 14,320 to 14,240 cal yr B.P.; BR92, 266 to 245 cm). Percentages and influx of *Abies* pollen increase. Many of the deciduous-tree taxa decrease (*Ulmus*, *Ostrya*/*Carpinus*, *Quercus*, *Juglans cinerea*, and *Fagus grandifolia*, but neither *Fraxinus* nor *Betula*). The pollen percentages of these deciduous-tree taxa are similar to their zone BR2 values. *Tsuga* pollen and macrofossils are absent. *Pinus* diploxydon-type pollen increases; *Picea* pollen influx increases. The pollen percentages of *Sanguisorba canadensis* increase while *Typha*/*Sparganium* decrease. Total pollen influx ranges from 4200 to 22,000 grains/cm<sup>2</sup>/yr.

Seeds from some shallow-water, temperate species, which were abundant in zone BR3a, are now absent. *Carex stipata*,

*Scirpus polyphyllus* type, and *S. atrovirens* type are now absent along with the herb *Verbena* cf. *hastata*. Definitive identification of these species is needed to interpret the environmental change. *Menyanthes trifoliata* seeds are present. Charcoal concentration ranges from 0 to 0.8 mm<sup>3</sup>/ml of sediment.

A reversal toward colder temperatures explains the rise in percentage and influx of *Abies* pollen, decreases in *Pinus* haploxydon-type pollen and *Pinus strobus* needles, and decreases in percentage and influx of the deciduous-tree taxa pollen. Other taxa showing increases in pollen influx—*Picea*, *Pinus* diploxydon-type pollen, and *S. canadensis*—are cold tolerant plants. *M. trifoliata*'s presence shows the pond had shallow water areas.

**Zone BR3c: *Picea*–*Abies*–*Ostrya*/*Carpinus*–*Quercus* zone** (12,200 to 11,280  $^{14}\text{C}$  yr B.P.; 14,240 to 13,260 cal yr B.P.; BR92, 245 to 195 cm). The pollen and macrofossil assemblage is very similar to that of zone BR3a except *Abies* macrofossils are absent and *Tsuga* needles are more abundant in BR3c. Total pollen influx ranges from 2200 to 6500 grains/cm<sup>2</sup>/yr. Pollen from *Lycopodium annotinum* and *M. trifoliata*, circumboreal species, and *S. canadensis* are last seen here.

Temperatures are inferred to warm and return to conditions like those of 12,730 to 12,260  $^{14}\text{C}$  yr B.P. (zone BR3a). Two more small *Tsuga*–*Pinus* haploxydon-type pollen and *Tsuga* macrofossil peaks (at 238 and 216 cm) could be related to

BR91, Plant Macrofossils

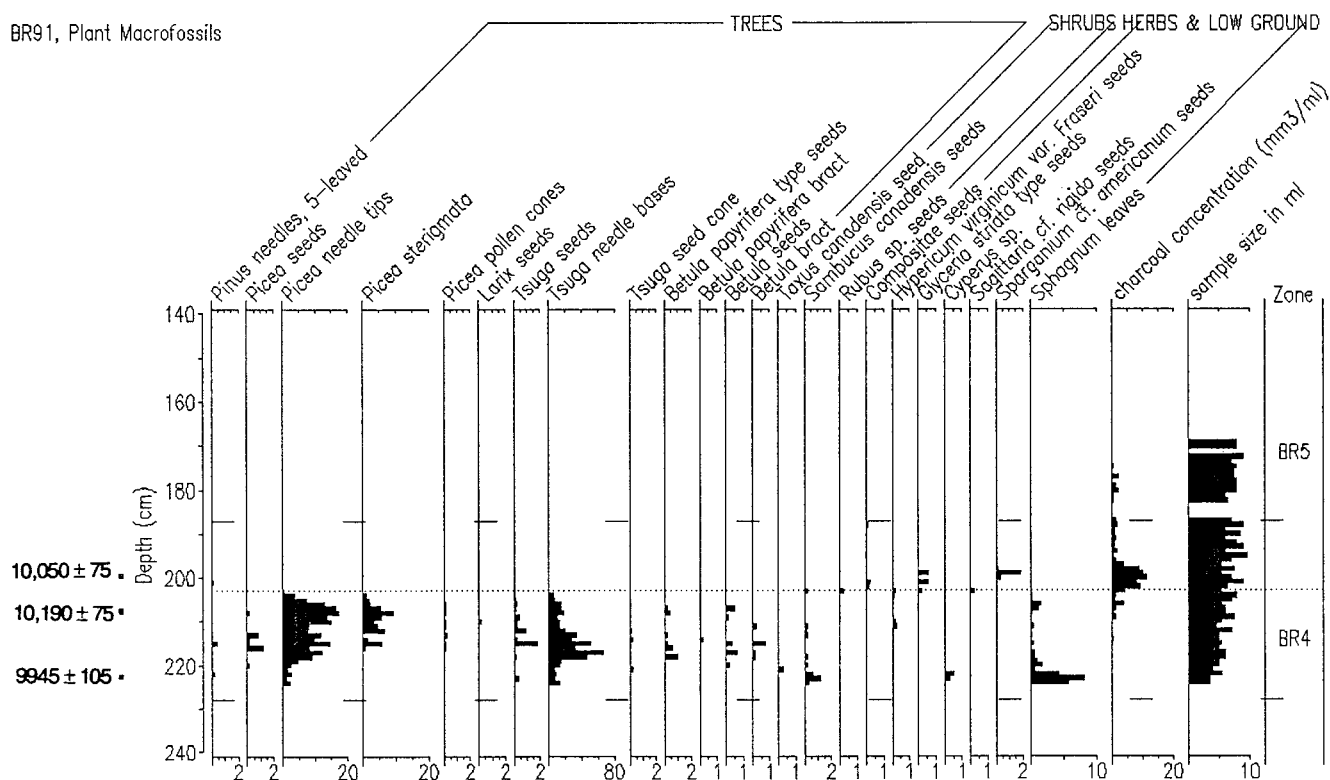


FIG. 4. Plant macrofossil and charcoal diagram from Core BR91. Fossils counts are normalized to a 1 ml sediment volume. Charcoal concentration is given in mm<sup>3</sup> per ml of sediment.

warming. This interpretation must be substantiated at additional sites.

At this point, the assemblages from both cores BR91 and BR92 are used to define the pollen zones. Pollen influx curves, and the CONISS results for core BR91 where our sampling resolution was higher, were all evaluated when making the divisions between zones BR3c, BR4, and BR5. Where the two cores overlap chronologically, the pollen and macrofossil assemblages are similar in composition, although differences exist in the exact percentage of any taxon counted and in the exact stratigraphic placement of fluctuations of one taxon relative to another. The differences could be due to factors affecting pollen accumulation within the basin (Davis *et al.*, 1984). Also, a core's proximity to the shoreline (itself a fluctuating feature over time) might register different ratios of the local and extra-local pollen sources, especially if the pollen was not well-mixed throughout the basin prior to deposition.

**Zone BR4:** *Tsuga-Betula-Pinus strobus*-zone (11,280 to 10,050 <sup>14</sup>C yr B.P.; 13,260 to approximately 10,940 cal yr B.P.; BR92, 195 to 173 cm; BR91, >225 to 203 cm). Dated fossils are near the beginning of the zone in core BR92 (BR91 did not penetrate all of zone BR4). Dating the top of zone BR4 is more subjective. In core BR92, the age of the 173 cm level is about 10,040 <sup>14</sup>C yr B.P. with our age model. However, in core BR91, the top of zone BR4 at 203 cm depth has an age

bracketed by three dates ranging from 9945 to 10,190 <sup>14</sup>C yr B.P. (Table 1). We approximate the end of zone BR4 at 10,050 <sup>14</sup>C yr B.P.

The dominance of *Tsuga* pollen (from 23 to 62% in BR92, 21 to 56% in BR91), distinct increases in *Betula* (reaching a maximum of 9.5% in BR92 and 20% in BR91) and *Pinus* haploxylon-type pollens, and a unique maximum in *Sphagnum* spores characterize this zone. Decreases in percentages of *Picea*, *Quercus*, Cyperaceae, and Tubuliflorae pollen accompany the *Tsuga* rise. Cyperaceae, *Abies*, and *Ostrya/Carpinus* pollen become rare. Total pollen influx is 2300 to 7200 grains/cm<sup>2</sup>/yr. The influx of *Tsuga*, *Betula*, and *Pinus* haploxylon-type pollens increases, but *Quercus* does not. Pollen from the aquatic plants, *Typha/Sparganium*, *Nuphar*, and *Sagittaria* decreases from the zone BR3c values.

*Tsuga* and *Picea* macrofossils are numerous, often exceeding 10 needle fragments each per 1 ml of sediment in core BR91. Two species of hemlock are recognized in eastern North America; *T. canadensis* is the most dispersed and *T. caroliniana* is confined to the Appalachians from Virginia to Georgia (Godman and Lancaster, 1990; Gleason and Cronquist, 1991). The three *Tsuga* seed-bearing (megasporeangiate) cones from this zone are more similar to *Tsuga canadensis* in length and scale shape. One entire *Picea* pollen-bearing (microsporeangiate) cone and several pollen-bearing cone fragments occur in



this zone (we could not identify the species). A few *P. strobus* needles and one *Larix* seed were found. *Betula* seeds and bracts are most abundant in this zone. Many of the *Betula* achenes are missing the wings and stigmas, and so species identification is difficult. Those *Betula* seeds that are finely pubescent just below the stigma were classified as *Betula papyrifera*-type (Cunningham, 1957). However the pubescent characteristic may not be unique to *B. papyrifera* (Radford *et al.*, 1968; Fernald, 1970; Gleason and Cronquist, 1991).

Seeds of *Sambucus canadensis*, a swamp shrub, and a single seed of the shade-tolerant shrub, *Taxus canadensis*, were identified. Decreases in *Nuphar* pollen, and the absence of Nymphaeaceae and *Nuphar* seeds, indicate water levels have dropped. Charcoal concentration in core BR91 ranges between 0 and 3.6 mm<sup>3</sup>/ml of sediment.

A temperature increase is inferred from the *Tsuga* increase and *Abies* decrease in both pollen and macrofossils. Throughout the Appalachians, *Tsuga* is now found at elevations lower than those at which *Abies* is found. The presence of *Picea* is consistent with warming temperatures if the species is *P. rubens*; this species is presently found with *Tsuga* and *P. strobus* in the central Appalachians (Eyre, 1980, p. 26–27). *Tsuga* is a long-lived (from 300 to 800 yr), very shade-tolerant tree that prefers a cool, humid climate (Rogers, 1978; Godman and Lancaster, 1990). *P. strobus* is tolerant of drier conditions, although the two trees may grow on more mesic sites or hummocks in wooded swamps (Jorgensen, 1978 p. 276; Powell, 1980).

**Zone BR5: *Nyssa*–*Tsuga*–*Quercus* zone (10,050 to 8410 <sup>14</sup>C yr B.P.; approximately 10,940 to approximately 9400 cal yr B.P.; BR92, 173 to 134 cm; BR91, 203 to <143 cm).** Within this zone *Quercus* replaces *Tsuga* as the dominant pollen taxon. A series of changes occurs in tree-taxa pollen in core BR92: *Nyssa* rises from 2.3% at 173 cm to a high of 10.5% at 145 cm, whereas at 152 cm *Picea* drops below 1% and *Abies* below 0.5%. *Diospyros* appears at 148 cm. Of all the taxa represented in the pollen diagrams, *Diospyros* unambiguously has the most southerly distribution, occurring below 41°N latitude and south to peninsular Florida (Halls, 1990). The same pollen sequence occurs in core BR91, although the percentages differ. Total influx ranges from 5000 to 1800 grains/cm<sup>2</sup>/yr at the end of this zone. *Quercus* influx increases gradually from 430 to 2100 grains/cm<sup>2</sup>/yr.

Macrofossils are nearly absent and the sediment is very inorganic. In BR92, a single *Cornus canadensis* seed was identified at 172 cm. In BR91, Compositae, *Glyceria striata*-type, and *Sparganium* cf. *americanum* seeds were found. The presense of *Typha*/*Sparganium* and *Polygonum lapathifolium*-type pollen and the absence of *Nuphar* pollen at the top of the zone, along with significant amounts of *Nyssa* pollen, indicate that the pond was largely replaced by wet ground or marshland. Charcoal concentrations are highest at the base of this zone. The concentrations in BR91 range from <1 to 8 mm<sup>3</sup>/ml of

sediment, whereas in core BR92 the maximum concentration is 2.9 mm<sup>3</sup>/ml of sediment. Thus, a fire and opening of the forest canopy are inferred. Increases in *Pteridium* and Polypodiaceae spores support this interpretation.

Warming temperatures explain the increasing influx of *Quercus*, *Nyssa*, and *Diospyros* and decreasing influx of *Tsuga* and *Betula* pollen. In zone BR5, the influx of *Quercus* pollen increases gradually, yet *Nyssa* and *Diospyros* exhibit rapid increases. A similar pattern occurs in concentration (Kneller, 1996). Possibly the local populations of *Nyssa* and *Diospyros* trees expanded more rapidly than *Quercus*. *Picea* pollen percentages fluctuate greatly; a single peak of 25% occurs at 181.5 cm, but in core BR92 there is much less fluctuation. The cause of the *Picea* fluctuations is unclear. The continued presence of significant *Tsuga* pollen supports the argument that climate was still as moist as at present in the southern low-elevation Appalachians.

**Zone BR6: *Quercus*–*Carya* zone (8410 to <4870 <sup>14</sup>C yr B.P.; approximately 9400 to 5600 cal yr B.P.; BR92, 134 to <65 cm).** *Carya* pollen, which has been at ca. 1% during the preceding zones, now rises to 4.4% at 134 cm and reaches a high of 11% at 72 cm. *Quercus* pollen ranges from 40 to 71% while *Tsuga* pollen decreases from 31 to <5% by 97 cm. Total pollen influx ranges from 2700 to 7600 grains/cm<sup>2</sup>/yr.

*Salix* buds and one seed each of *Crataegus* and *Rubus* were identified. Aquatic and low-ground plant seeds come from several *Carex* species, *Polygonum* cf. *punctatum*, and at least three *Potamogeton* species. Characeae oogonia are present. Charcoal concentration ranges from <1 to 4.5 mm<sup>3</sup>/ml of sediment.

Fluctuations in water quality and depth can explain the variations in aquatic and wet ground taxa. The pollen of swamp-ground taxa, *Ilex* and *Cephalanthus occidentalis*, occur throughout the zone. Their percentages decrease slightly as *Nuphar* pollen returns above 100 cm depth, which indicates an increase in water levels.

At 7500 <sup>14</sup>C yr B.P., a brief return to a colder, but still moist, climate is inferred from the resurgence in *Tsuga* (16%), *Picea* (4.5%), and *Abies* (1.0%) pollen. The increases (from a single sample at 103 cm depth) are noticeable in the concentration diagram and just perceptible in influx. The fact that three cold-tolerant taxa exhibit synchronous increases in pollen percentage, concentration, and influx points to a short reversal to colder temperatures. However, because this conclusion depends on a single sample, other sites must be found to substantiate the local and regional significance of the cold reversal.

#### Water-Level Fluctuations

Previously we inferred water-level fluctuations in Browns Pond based on changes in aquatic plants and the lithostratigraphy. We proposed that the lowest lake levels occurred from 10,000 to 8000 <sup>14</sup>C yr B.P. (Kneller and Peteet, 1993). An inorganic sand–clay layer with slower sediment accumulation

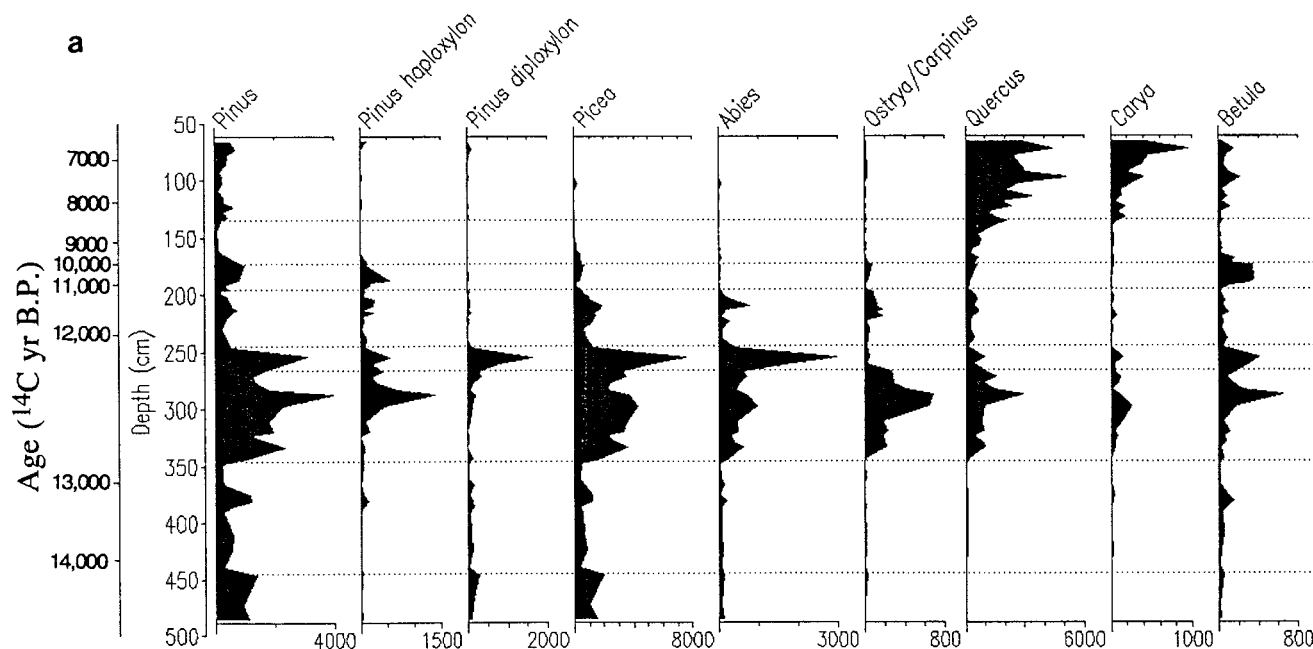


FIG. 5. Pollen accumulation rate (PAR), or pollen influx, diagram for selected taxa in core BR92. The age axis is based on the assumption of a constant accumulation rate between radiocarbon dates. Note that the horizontal axis changes in scale for each pollen taxa. Units of PAR are in number of pollen grains per  $\text{cm}^2$  per year.

rates and a decrease in aquatic pollen percentages was identified between 176 and 130 cm depth in the previously studied central core, BR89. This inorganic layer occurred in five additional cores taken in a transect across the pond. We hypothesized that a lowering in water-level depth, driven by climate, had created this relatively inorganic layer dating to the early Holocene.

The new analysis of cores BR92 and BR91 substantiates the earlier conclusion that the pond's water levels were lowest during the early Holocene. Based on the lithostratigraphy and organic content measurements, the inorganic clay layer is between 210 and 164 cm depth in core BR91 and 186 and 140 cm depth in BR92 (Kneller, 1996). In these cores, the period of low organic content and slowest accumulation rates occurs between ca. 10,000 and 8500  $^{14}\text{C}$  yr B.P. During this time aquatics, perhaps best exemplified by *Nuphar*, are at their lowest percentages. However, the trees represented in the pollen assemblage require moist conditions. Today, *Tsuga* grows in regions where annual precipitation ranges from <740 to 1270 mm (Godman and Lancaster, 1990). *Nyssa* and *Diospyros*, which co-occur in the pollen assemblage with *Tsuga* from 10,000 to 7500  $^{14}\text{C}$  yr B.P., now grow where annual average precipitation is at least 1000 mm and often exceeds 1200 mm (Halls, 1990; Johnson, 1990; Kossuth and Scheer, 1990; McGee, 1990; Outcalt, 1990). Apparently, annual average precipitation was approximately equal to present values, even as the pond's water levels were lower than present.

The apparent lower water level without a decrease in pre-

cipitation might be explained by increased evaporation, increased drought frequency, infilling of the pond, a changing depositional center over time, or some combination of climate and nonclimatic factors. Determining the cause of the water-level fluctuations is difficult because the basin is, and likely always was, irregular in shape (i.e., not perfectly conical). Thus, very likely, sediment and pollen have accumulated at varying rates across the pond (Davis *et al.*, 1984), and the locations of the depositional center and shoreline have shifted over time. For example, the beginning of the *Alnus-Picea-Pinus* zone occurs at 445 cm depth (14,100  $^{14}\text{C}$  yr B.P.) in BR92, yet lies at 337 cm depth (14,090  $^{14}\text{C}$  yr B.P.) in core BR89. Thus, at 14,000  $^{14}\text{C}$  yr B.P., core BR92 was in the deeper section of the pond. Total pollen influx also differs between cores BR92 and BR89. The differences could be caused by depositional or postdepositional (e.g., erosional or oxidational) processes (Donner *et al.*, 1978; Davis *et al.*, 1984). Evidence for changes in water quality also comes from *Sphagnum* and Characeae, which occur in acidic and basic conditions, respectively. In cores BR89 and BR92, Characeae oogonia were identified from the bottom of the cores up to approximately 12,730  $^{14}\text{C}$  yr B.P., when *Sphagnum* leaves or spores occur. At approximately 8000  $^{14}\text{C}$  yr B.P., *Sphagnum* disappears and Characeae oogonia reappear. A complete gridded transect of the pond would be necessary to determine conclusively which inferred changes in water level represent a basin-wide drop in water level.

b

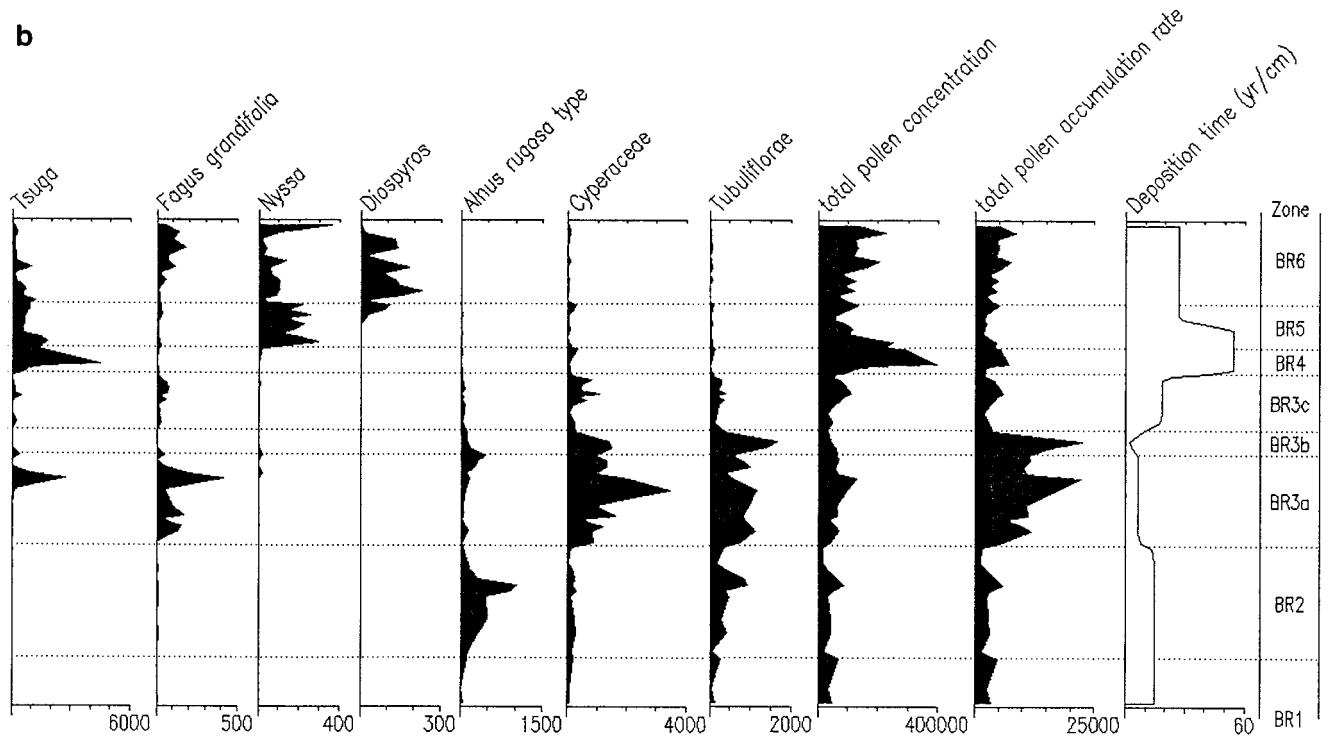


FIG. 5—Continued

## DISCUSSION

Questions remain about this record of late-glacial/early Holocene vegetation. First, if the *Picea* species present at anytime at Browns Pond is *P. glauca* or *P. mariana* and not *P. rubens*, would this substantially change the climatological interpretations? In Pennsylvania, Watts (1979) tentatively identified pollen from all three spruce species in late-glacial sediments. However, for the reasons stated by Delcourt (1979), we were unable to identify definitively the species of our spruce pollen and macrofossils. Each species has different climatological and ecological affinities. Definitive identification of the species would aid in the environmental reconstruction. Second, how accurate is the qualitative climate interpretation based on analogy with the montane forests of the Appalachian Mountains? Quantitative climate reconstructions could be made by statistically comparing each fossil pollen spectrum with modern pollen surface samples obtained from throughout North America. However, several issues must be resolved before proceeding with the statistical comparisons. The fossil pollen spectra recorded in each of the three radiocarbon-dated cores (BR89, BR91, and BR92) agree qualitatively, but not quantitatively, with each other. For example, in the late-glacial sediments, the ratio of *Picea* to *Pinus*, or *Picea* to *Alnus*, varies between cores BR89 and BR92 (see description of the pollen zones). Distance of each core to the shoreline might partially explain the different percentages recorded. Additional modern pollen surface samples from the Appalachians are needed to capture the full

range of plant associations recognized in the modern phyto-geographic studies.

The sequence of temperature fluctuations interpreted at this central Appalachian site shows striking similarities and dissimilarities with the sequence of events in other pollen stratigraphies and polar ice cores from the North Atlantic region. We interpret temperatures cooler than present from 14,180 to 10,000  $^{14}\text{C}$  yr B.P.

The step toward warming at 12,730  $^{14}\text{C}$  yr B.P. seen at Browns Pond probably represents a change over much of the southeastern United States because sites in Tennessee (Delcourt, 1979), South Carolina (Watts, 1980), and Florida (Watts and Hansen, 1994) show increases in temperate pollen taxa (*Quercus*, *Carya*, *Fagus*, *Fraxinus*, and *Ostrya/Carpinus*) between 12,800 and 12,500  $^{14}\text{C}$  yr B.P. This warming is contemporary with warmings seen in pollen records from the northeastern United States (Peteet *et al.*, 1993, 1994; Maenza-Gmelch, 1997a, 1997b). Thus, the warming may have been synchronous from ca. 29° to 41°N latitude along the eastern margin of North America. It should be substantiated by evaluating additional sites, especially since a radiocarbon plateau of constant  $^{14}\text{C}$  age occurs at this time (Ammann and Lotter, 1989; Kitagawa and van der Plicht, 1998). The North American warming may also coincide with the onset of warming inferred from pollen records in northern and western Europe (Björck and Möller, 1987; Ammann and Lotter, 1989; Watts *et al.*, 1996) and the abrupt rise in delta  $^{18}\text{O}$  (Johnsen *et al.*, 1992;

**TABLE 1**  
**Radiocarbon and Calibrated Ages for Dated Samples from Cores BR91 and BR92**

Sample number	Sample depth (cm)	Material dated	Dry weight (mg)	Age ( $^{14}\text{C}$ yr B.P.)	Age (cal yr B.P.) <sup>a</sup>
Core BR92					
NSF Arizona AA 17723	100	1 <i>Carex lupulina</i> seed 2 <i>C. crinita</i> seeds 2 conifer cone scales 4 <i>Salix</i> buds	2.65	7500 $\pm$ 60	8310, 8220, 8218 (8339–8171)
Lawrence Livermore 17319	152.0	Sediment	4100	8890 $\pm$ 60	9906 (9969–9870)
17322	194.8–196.4	4 <i>Picea</i> needle bases 2 <i>Picea</i> needle tips 4 needle fragments 1 <i>Alnus</i> cone scale (partial)	2.37	11,280 $\pm$ 60	13,190 (13,280–13,110)
17323	244.0–245.6	3 <i>Picea</i> needle bases 2 <i>Picea</i> needle tips 6 <i>Picea</i> sterigmata 4 needle fragments 5 <i>Carix lurida</i> seeds	2.75	12,200 $\pm$ 70	14,240 (14,406–14,091)
17324	259.8–261.4	2 <i>Picea</i> needles 2 <i>Picea</i> needle bases 3 <i>Rubus</i> seeds Nut fragment	3.27	12,230 $\pm$ 70	14,278 (14,446–14,127)
17325	344.7–346.0	1 <i>Picea</i> needle Partial conifer needle 17 <i>Picea</i> sterigmata Conifer cone bract $\frac{1}{3}$ <i>Rubus</i> seed 3 $\frac{2}{3}$ <i>Carex lurida</i> seed $\frac{1}{2}$ Nymphaeaceae seed <i>Menyanthes</i> fragment	3.78	12,730 $\pm$ 60	15,001 (15,173–14,812)
17326	445.0	Sediment	2300	14,180 $\pm$ 60	17,004 (17,115–16,895)
Core BR91					
NSF Arizona AA 17724	199.0–200.0	8 <i>Sparganium</i> seeds	4.45	10,050 $\pm$ 75	11,464–11,225 11,828–11,050
AA 17725	207.0–208.0	23 <i>Picea</i> needle pieces 2 <i>Picea</i> sterigmata 2 <i>Tsuga</i> stem fragments 10 <i>Tsuga</i> needle bases	2.2	10,190 $\pm$ 75	11,939 (12,134–11,659)
AA 17726	222.0–223.0	18 <i>Picea</i> needle pieces 38 <i>Tsuga</i> needle bases 2 <i>Tsuga</i> stem pieces 2 <i>Sambucus</i> seeds	2.1	9945 $\pm$ 105	11,073, 11,061, 11,034 (11,536–10,996)

<sup>a</sup> The first number (or set of numbers) is the calibrated age. The numbers in the parentheses are the range of the calibrated age at the one sigma level. Sample AA 17724 has nine calibrated ages; only the youngest and oldest are printed here.

Björck *et al.*, 1998) and snow accumulation rates (Alley *et al.*, 1993) in Greenland ice cores.

The Browns Pond record shows cold reversals at 12,200 and

7500  $^{14}\text{C}$  yr B.P., superimposed upon the overall warming trend. The first reversal (centered at about 14,280 cal yr B.P.) may correlate with the European Older Dryas chronozone,



which Mangerud *et al.*, (1974) placed between 12,000 and 11,800  $^{14}\text{C}$  yr B.P. Subsequent palynology in Sweden revised the dating of the Older Dryas chronozone to between 12,150 and 12,000  $^{14}\text{C}$  yr B.P. (Björck, 1984; Björck and Möller, 1987). The second cold reversal dates to 7500  $^{14}\text{C}$  yr B.P. (between 8300 and 8200 cal yr B.P.). It coincides with  $\text{CH}_4$  minimums in the GRIP and GISP2 ice cores and the most noticeable Holocene decrease in delta  $^{18}\text{O}_{\text{ice}}$  (Chappellaz *et al.*, 1993; Sowers and Bender, 1995; Alley *et al.*, 1997). It also coincides with an ice-rafting event in the North Atlantic Ocean linked to changes in surface circulation (Bond *et al.*, 1997) and with a 200-yr cooling inferred from oxygen isotopes in Lake Ammersee, Germany (von Grafenstein *et al.*, 1998). The cold reversals at this site in the central Appalachians may be concurrent with cold events in the northern high latitudes and shifts in trade-wind strength in the tropical Atlantic Ocean (Hughen *et al.*, 1996; Björck *et al.*, 1998). However, the inherent errors in radiocarbon dating, and the samples' statistical errors, leave room for uncertainty.

The shift to a relatively warmer climate at 11,350  $^{14}\text{C}$  yr B.P. is significant, for it may show the southern limit of cooling on the eastern margin of North America, contemporaneous with the Younger Dryas chronozone. The late-glacial rise in hemlock and decrease in fir pollen, which indicate warming at Browns Pond, are also apparent at two sites just to the north [Buckles Bog, 39°34'N 79°16'W (Maxwell and Davis, 1972) and Big Run Bog, 39°07'N, 70°35'W (Larabee, 1986)], although the timing is less well-constrained. Other records in the southeastern United States do not clearly show a cooling at this time. Only at Jackson Pond, Kentucky, have *Picea* fluctuations from 11,300 and 10,040  $^{14}\text{C}$  yr B.P. been hypothesized to represent a Younger Dryas climate oscillation (Wilkins *et al.*, 1991).

Increasing warmth and moisture at 11,300  $^{14}\text{C}$  yr B.P. in the central Appalachians can be consistent with a cold reversal in the northern North Atlantic region. If a steep temperature gradient exists between cold subpolar waters and warmer subtropical waters, then storm-track-associated moisture will be concentrated along the maximum thermal gradient. GCM climate simulations support this hypothesis: when northern North Atlantic sea-surface temperatures were cooled, a net increase in precipitation minus evaporation occurred at the southern edge of strong temperature contrast (Rind *et al.*, 1986; Keffer *et al.*, 1988). The global extent of a cold reversal contemporaneous with the Younger Dryas chronozone (11,000 to 10,000  $^{14}\text{C}$  yr B.P.) and its causes is still in debate (Peteet, 1995).

Ideally, other unglaciated east coast sites with high-resolution chronologies are needed to confirm the timing, and to define the regionality, of the brief cold reversals seen here in the central Appalachians. The diversity of vegetation and close proximity of ecotonal boundaries in this region permit a rapid response of the vegetation to changing climate. The great similarity in the timing of climate events seen in this terrestrial midlatitude vegetation record, when compared to polar ice core

and northern European pollen records, suggests a strong coupling of the atmosphere–ocean climate system.

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